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Study Made of Dielectric Properties of Promising Materials for Cryogenic Capacitors

Experimental investigations were conducted in an effort to determine dielectric properties of promising materials for cryogenic capacitors to be used in energy storage and pulse applications. Dielectric data were obtained on promising materials, including screening tests, tests in liquid nitrogen, and techniques for winding or stacking small test capacitors. Three classes of materials were investigated: (1) inorganic bonded ferroelectric materials; (2) anodic coatings on metal foils; and (3) polar low temperature liquids.

The work done on this program is summarized below.

Permittivity and Dielectric Loss: A considerable understanding of the properties of dielectrics at cryogenic temperatures has been developed which provides a reasonable basis for judging their potential usefulness as cryogenic dielectrics in capacitors. Values of permittivity from 20 to as high as 38 have been achieved in ferroelectric powder films impregnated with liquid nitrogen. The permittivity can be increased still further by impregnation with polar liquids such as 1-nitropropane and a number of special silicone fluids. The greatest advantage from such impregnation is achieved when a temperature is selected for which the permittivity is maximum and the dissipation factor is minimum. In this respect, the silicone liquids are superior. It should be recognized that temperature control may pose difficulties in practical capacitors but the refrigeration costs at the lower temperatures (-105°C for example) will be less than for liquid nitrogen at -196°C .

The polar, high permittivity liquids are of interest as impregnants for ferroelectric powder film but have not been as interesting so far as impregnants for porous sheet dielectrics such as paper. However, this ap-

proach might benefit from greater study particularly in the direction of low density and perhaps synthetic fiber sheet.

The use of anodic coatings at cryogenic temperatures has received only very limited study and to date high values of permittivity have not been achieved. This approach does not appear to be promising.

Voltage Breakdown: The values of voltage breakdown achieved have been disappointing. Part of the problem involves the use of single film dielectrics which has been made necessary by mechanical limitations. In conventional capacitors, multiple layer insulation is used to avoid the registry of the faults found in single layers. Only in capacitors with evaporated metal electrodes can single dielectric films normally be used. The thin metal is sputtered away from areas of failure by the application of voltage with a high resistance in series to limit the current. Evaporated metal electrodes could be used in the cryogenic design but might constitute a limitation in discharge applications.

Mechanical Characteristics of Dielectric Materials: To achieve high values of permittivity in ferroelectric powder films, it is necessary to use very large ratios of powder to binder. Such large ratios also lead to somewhat porous films which can be impregnated with liquid. However, with such a small percentage of binder, it is difficult to obtain good mechanical strengths. In consequence, the aluminum foil has been used to provide the needed mechanical strength and to act as a "carrier" for the insulating film which is coated on it. Obviously, problems develop when a 0.00025-in. aluminum foil is required to "carry" a heavy 0.002-in. insulating film. It seems unlikely that

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such a film can be wound with conventional capacitor winding equipment, at least at usual winding speeds.

When the dielectric film is cast directly on the aluminum foil, no dielectric will "protect" the edge of the film unless the insulating film can project beyond the edges (be wider than the foil). So far it has been impossible to make the insulating film wider than the foil.

The Overall Material Problem: From the foregoing it is apparent that the electrical objectives for a cryogenic capacitor dielectric have been achieved although improvement is to be desired in electric strength. The mechanical characteristics needed for a practical cryogenic capacitor have not been achieved but approaches to the solution of the problem have been suggested. The mechanical problems should be solved and a suitable unsupported dielectric film should be developed before construction of prototype cryogenic capacitors is attempted. As an alternative, new methods of winding or assembling capacitors might be developed.

Cryogenic Capacitor Design: Estimates are made of size, weight, and losses for cryogenic capacitor systems, using as a basis the dielectric parameters developed during the course of this investigation. These data may be used to form a tentative evaluation of the potential payoff of successful development. In general, the data indicate that relatively compact capaci-

tor systems are possible. This is especially true if the cases where the more optimistic estimates of dielectric capability are used. Refrigeration loads and/or nitrogen consumption are quite reasonable, as well as system volumes and weights, compared to more conventional approaches. The peripheral components required to construct a cryogenic capacitor system are well developed and essentially state-of-the-art. The principal unknown is the complexity of the development task to perfect the dielectric system itself.

Notes:

1. Additional details, are contained in: "Cryogenic Capacitor Investigation," by K. N. Mathes and S. H. Minnich, Final Report S-67-1095, General Electric, May 1967.
2. Copies of this report may be obtained from:
Technology Utilization Officer
Marshall Space Flight Center
Huntsville, Alabama 35812
Reference: B67-10366

Patent status:

No patent action is contemplated by NASA.

Source: K. N. Mathes and S. H. Minnich
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